

## FURTHER OXYGEN ISOTOPE MEASUREMENTS FOR TWO COMETARY IMPACT CRATER RESIDUES: STILL LIKE CHONDRITES. C. J. Snead<sup>1</sup>, K. D. McKeegan<sup>1</sup>, P. Boehnke<sup>1</sup> and A.T. Kearsley<sup>2,3</sup>

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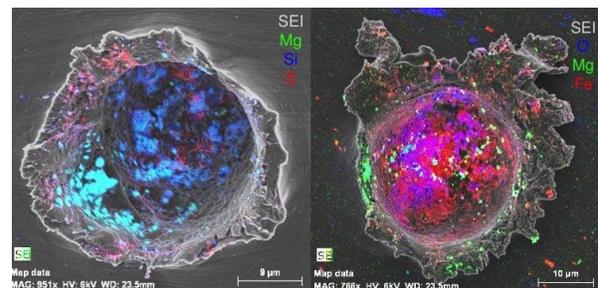
**Introduction:** The NASA Stardust mission successfully returned samples from comet 81P/Wild 2 and provided, for the first time, an opportunity to measure the bulk oxygen isotope composition comet dust. Precision measurements of material from a Kuiper belt object have the potential to constrain models for the origin and evolution of oxygen isotope heterogeneities in the early solar nebula.  $\delta^{17}\text{O}$  and  $\delta^{18}\text{O}$  values of calcium-aluminum rich inclusions define a mixing line of slope  $\sim 1$  between a  $^{16}\text{O}$  rich reservoir and a relatively  $^{16}\text{O}$  poor reservoir [1]. Results from the Genesis mission place the Sun near the  $^{16}\text{O}$ -rich end of the CAI mixing line [2]; therefore, some mass-independent process enriched planetary materials in proportionally equal amounts of  $^{17}\text{O}$  and  $^{18}\text{O}$ . UV photodissociation has been suggested as the mechanism for producing such a  $^{17}\text{O}$  and  $^{18}\text{O}$  enriched reservoir [3]. One prediction of a UV self-shielding model is that primordial ice should have a composition of  $\sim 200\text{-}300\%$  whereas dust should have a  $^{16}\text{O}$ -rich composition close to solar ( $\sim 60\%$ ). Thus far, oxygen isotope measurements of grains recovered from aerogel tracks have yet to confirm this prediction; instead, measurements have revealed surprising similarities to minerals in carbonaceous chondrites which have been interpreted as evidence for large scale radial migration of dust components from the inner solar nebula to the accretion regions of Jupiter-family comets [4]. If this interpretation is correct, what these studies have so far not achieved is a measurement of the average oxygen isotope composition of the dust component of material that formed and accreted in the distal cold regions of the nebula (well beyond the snow line).

Synchrotron X-ray analyses of Stardust aerogel tracks suggest that in at least some tracks, 65-90% of the impactor mass resides in the upper portion of bulbous and carrot shaped aerogel tracks as submicron particles, while the larger ( $>1\mu\text{m}$ ) more robust terminal particles represent only 10-35% of the total mass of the impactor [5]. These analyses have led to a model (e.g. see Fig 11 of [6]) of impacting Wild 2 dust as aggregates of loosely bound fine-grained material containing the occasional larger olivine, pyroxene, iron sulfide and iron oxide grains. The fine grained component suffered intimate mixing with the oxygen-rich aerogel, making definitive oxygen isotope analysis of these materials extremely challenging.

The aluminum foil substrates on the Stardust collector provided an auxiliary, low oxygen background alternative to the aerogel for measuring both coarse and fine-grained components of impacting Wild 2 dust particles. Numerous laboratory hypervelocity impact experiments demonstrate that at the encounter velocity of Stardust with Wild 2 craters in aluminum foils likely retain much of the impacting cometary material in a well defined location (the crater), regardless of impactor grain size. In addition, large, single mineral impactors can be distinguished from fine-grained cluster impactors by examination of crater morphology. We used the light gas gun at the University of Kent in Canterbury to fire particles of known isotopic composition into aluminum foil targets to assess potential fractionation effects resulting from hypervelocity capture. These effects have been found to be consistent at Stardust encounter velocities, and can be used to normalize measurements of Stardust impact crater residues.

We previously reported results of oxygen isotope measurements of two Stardust impact crater residues [7]; those values were found to plot on the terrestrial fraction line. Here we report results for two additional Stardust craters, C2104W,4 and C2031W,3.

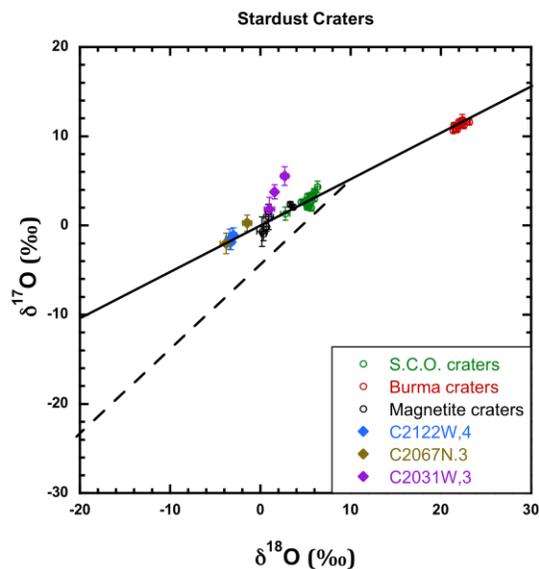
**Techniques and Results:** Energy dispersive X-ray mapping of craters C2104 and C2031 was performed with a Bruker XFlash quad detector at the Natural History Museum, London. C2031 was determined to be a Mg-rich olivine/pyroxene mix, with traces of FeS. The C2104 crater residue contained abundant Fe, Ni, and S with trace oxygen on the crater floor; the oxygen did not appear to be strongly correlated with other crater residues, leading to suspicion that it represented contamination or oxidation that occurred after capture.



**Figure 1:** Secondary electron images of C2031, W,3 (left) and C2104, W,4 (right), overlain by X-ray maps for Mg (green in both), Si (blue in left), O (blue in right), S (red in left) and Fe (red in right).

The craters were then cut from the foil targets, flattened and pressed into indium-filled reservoirs in 1" polished aluminum ion probe mounts. Each ion probe mount also contained a polished mineral standard (Afrique magnetite for C2104, and San Carlos olivine for C2031) at its center, as well as seven corresponding synthetic impact craters of the mineral standards.

Oxygen isotopes were measured using a Cameca IMS-1270 ion probe with a 20keV, 0.5nA cesium primary beam of  $\sim 25\mu\text{m}$  diameter. The detection system was configured for 3-oxygen isotope multicollection, with  $^{16}\text{O}$  measured on a Faraday cup, and  $^{17}\text{O}$  and  $^{18}\text{O}$  measured on electron multipliers. Individual crater analyses consisted of 100 count cycles of 5 seconds per cycle. All sputtered ions were counted (i.e. we did not use a fixed presputter). After applying background, yield and deadtime corrections, we performed a change-point analysis on our data via R [8,9] in order to determine when the sample reached sputtering equilibrium; data points collected prior to the change point were excluded. Change-point analysis was also used to determine whether the residue had completely sputtered (which was observed for C2031).



**Figure 2:** Measurements of craters C2122W,4, C2067N,3 and C2031,W,3 normalized to Afrique Magnetite and San Carlos olivine simulated crater impacts.

Analysis of C2104 revealed an  $^{16}\text{O}$  count rate that fell below  $5 \times 10^6$  counts per second within the first 50 cycles of analysis, which is more indicative of oxide layers of blank aluminum foil analyses rather than of crater residues [10]. These results, as well as the weak correlation between the oxygen and the residue in the

SEM analysis lead us to conclude that the residue was originally an Fe/Ni sulfide or metal that oxidized terrestrially.

Three analyses of C2031W,3 yielded crater normalized  $\delta^{18}\text{O}$  values of  $1.0 \pm 0.6\text{‰}$ ,  $1.6 \pm 0.3\text{‰}$  and  $2.7 \pm 0.4\text{‰}$  (1 s.e.) and crater normalized  $\delta^{17}\text{O}$  values of  $1.8 \pm 1.3\text{‰}$ ,  $3.8 \pm 0.8\text{‰}$  and  $5.6 \pm 1.0\text{‰}$  (1 s.e.). These values fall within the range of bulk ordinary chondrite measurements, and are consistent with some measurements of particles extracted from aerogel tracks [11]. Thus far, none of the analyzed crater residues have  $^{16}\text{O}$ -rich compositions that are predicted for comet dust by UV self-shielding models, though the sample size is small. We plan to measure ten more Stardust crater residues in the future in order to report a bulk oxygen isotopic composition of comet 81P/Wild 2 dust.

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**References:** [1] Clayton R. N. et al. (1973) *Science*, 182, 485-488. [2] McKeegan K. D. et al. (2011) *Science*, 332, 1528-1532. [3] Clayton, R.N. (2002) *Nature*, 415, 860-861. [4] McKeegan, K.D. et al. (2006) *Science*, 314, 1724-1728. [5] Flynn G. J. et al. (2006) *Science*, 314, 1731-1735. [6] Kearsley A.T. et al. (2009) *Meteoritics & Planet. Sci.*, 44 1489-1510. [7] Snead C. J. (2014) *LPS XLV*, Abstract #2928. [8] R CoreW Team (2013) *R Foundation for Statistical Computing*, Vienna, Austria. [9] Killick, R. and Eckley, I (2013) *R package*. [10] Snead, C.J. et al. 77<sup>th</sup> *Meteoritical Society*, Abstract #5330. [11] Nakamura T. et al. (2008) *Science*, 321, 1664-1667.